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Forest Science Program

Vegetation Response, Fire Effects, and Tree Growth after Slashburning in the Engelmann Spruce–Subalpine Fir Zone: Goat River Site

Evelyn H. Hamilton

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ABSTRACT

Fire effects, and vegetation and seedling response to burning, were monitored for 10 years after slashburning on the Goat River site. A fire weather station and gravimetric sampling were used to determine fire weather codes and indices and forest floor moisture content. Fuel loading, fuel consumption, and burn severity were ascertained using fuel assessment triangles and permanent plots. Changes in floristic composition and structure (cover and height) were documented along with survival and growth of planted hybrid white spruce seedlings.

The patchy burn was of fairly low severity, with little mineral soil exposure or large fuel consumption. When measured forest floor moisture content was used as an input, duff and fuel consumption as well as mineral soil exposure were less than predicted by the Prescribed Fire Predictor.

After the site was logged and burned, the vegetation structure at ground level shifted from a community dominated by bryophytes and small herbs to a young conifer forest with mosses, taller herbs, and shrubs. After 10 years, bryophyte cover was 77%, which was comparable to pre-burn levels (82%), herb cover was 14% or approximately one-half of pre-burn levels (24%), and shrub cover was 12% or double the pre-burn levels (6.5%). Shrubs were the tallest life form after the site was logged, but they had not regained pre-burn heights 10 years after burning. Although some of the original forest species were lost, a number of new species established from seed banks and off-plot sources.

Most of the native vascular species diversity was maintained on the plots, but a number of invasive species established. The ericaceous shrubs typical of Engelmann Spruce–Subalpine Fir (ESSF) biogeoclimatic zone sites were not as well adapted to burning as were the species more typical of lower-elevation forests. This would be expected, given the more frequent fires typical of the lower-elevation forests.

The planted spruce seedlings met "free-growing" requirements 10 growing seasons or years after burning. Average tree height after 10 years was 187 cm and average root collar diameter was 5.2 cm. Survival was 77%. More complete burning led to taller shrub and herb vegetation 1 year after burning. This was attributed, in part, to the enhanced invasion of fireweed into burned microsites. Taller vegetation resulted in increased shading of conifer seedlings and increased vegetation press, which reduced tree seedling growth.

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1 INTRODUCTION

1.1 Background

Clearcutting and slashburning have been widely practised in British Columbia, but little is known about subsequent patterns of vegetation development or conifer growth or how slashburn severity influences these. Hamilton and Yearsley (1988) provided preliminary models of forest vegetation succession that helped to facilitate integration of forest regeneration with wildlife habitat and biodiversity needs and to assist in the development of a seral classification within the biogeoclimatic ecosystem classification.

A number of site-specific studies on other ESSF sites have demonstrated the effects of fires of varying severity on vegetation development and tree growth (Hamilton and Peterson 2003, 2006; Hamilton 2006a). The information gathered from this and other studies has been synthesized into a summary of post-fire vegetation development in central British Columbia (Hamilton and Haeussler, in press).

Although much is known about the ecology, including light, temperature and nutrient relationships, and response of hybrid white spruce to some silvicultural treatments (Coates et al. 1994), relatively little has been published on the effects of prescribed burning on seedling survival and growth in subalpine environments.

The Canadian Forest Fire Weather Index System (CFFWIS) (van Wagner 1987) has been used in British Columbia along with the Prescribed Fire Predictor (PFP) (Muraro 1975) to determine when sites should be burned. The PFP predicts duff consumption, mineral soil exposure, and fuel consumption for different size classes of fuel on the basis of CFFWIS codes, including Duff Moisture Code (DMC) and Drought Code (DC), and site slope class. Region- and ecosystem-specific equations to convert DMC and DC to moisture content have been developed for forests in the southern Yukon and southern interior of British Columbia (Lawson et al. 1997a; Lawson et al. 1997b) to help improve the predictions of forest floor moisture content and consumption over those based on the National Standard DMC. A comparison of the predicted and measured DMC and DC are made in this study.

This technical report presents the 10-year results for the Goat River study (EP 1093.02). Fire effects, vegetation development, and tree response were monitored for 10 years after clearcutting and slashburning in permanent plots.

1.2 Objectives

The objectives of this study are:

1. to document the effects of a prescribed slashburn on the forest floor, fuels, and vegetation;
2. to determine the relationship between predicted and actual forest floor moisture content and between predicted and actual fuel and duff consumption on this site;
3. to quantify and describe changes in percent cover, height, species composition, and diversity of vegetation following burning;
4. to quantify and describe the growth and mortality of planted hybrid white spruce (*Picea glauca* × *engelmannii*) seedlings after burning; and
5. to determine the relationship between tree seedling growth and fire effects and vegetation levels.

1.3 Study Area

The study is located on Cutting Permit 107 in the Headwaters Forest District of the Southern Interior Forest Region, near kilometre 19.5 on the Goat River Forest Service road (see Figures 1 and 2). The cutblock is situated between 1100 and 1140 m in elevation. Although mapped as the Wet Cool Goat variant of the Interior Cedar–Hemlock Zone (ICHwk3) on biogeoclimatic maps, the site appears to be a cold-air drainage pocket of the Wet Cool Cariboo variant of the Engelmann Spruce–Subalpine Fir Zone (ESSFwk1) (DeLong and Meidinger 1996). This area is at the southern extent of the ESSFwk1 subzone variant and is transitional to the ESSFmm subzone.

Before logging, the mature forest was dominated by subalpine fir (*Abies lasiocarpa*) and hybrid white spruce (*Picea engelmannii × glauca*), with some western hemlock (*Tsuga heterophylla*). The site most closely resembles the ESSFwk1/01 or Subalpine fir – Oak fern – Brachythecium site series (DeLong and Meidinger 1996). It lacks *Oplopanax horridus, Orthilia secunda, Aralia nudicaulis, Tiarella* spp., and other species often found in the ICHwk3 variant. Some *Rhododendron albiflorum* is present, which is typical of the ESSFwk1 subzone variant. The site lacks some typical ESSFwk1/01 species, such as *Valeriana sitchensis* and *Veratrum viride*; the site also has some *Sphagnum*, which is characteristic of wetter site series. (See Appendix 1 for a list of common and scientific names.)

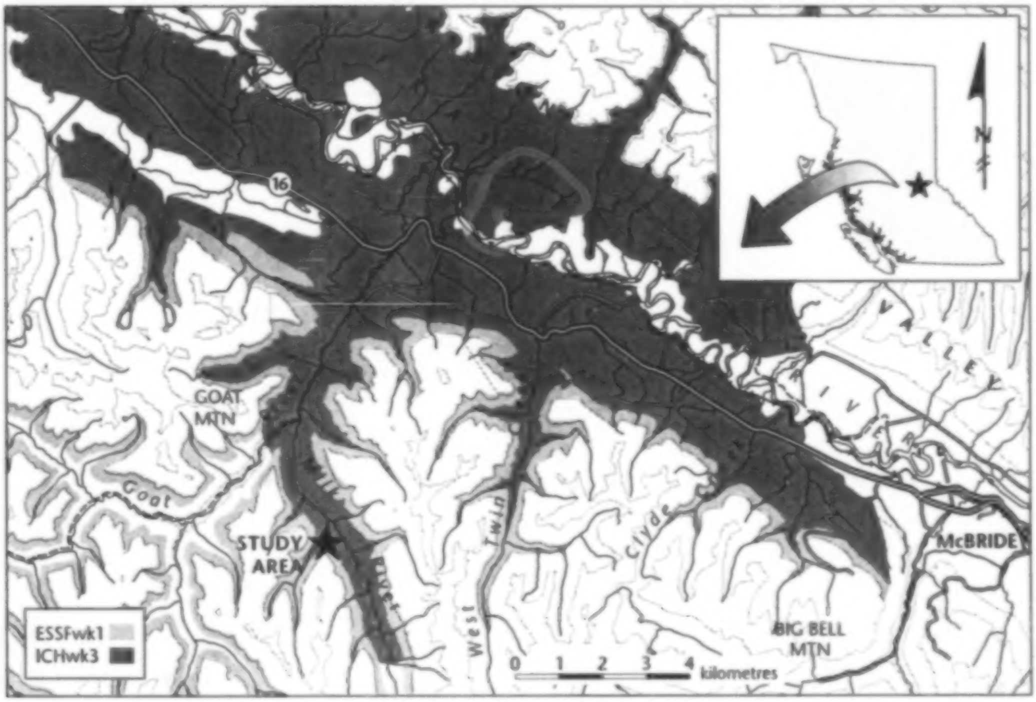

FIGURE 1 *Location of the Goat River study area (based on the biogeoclimatic subzone map from the Ministry of Forests and Range database, September 2002).*

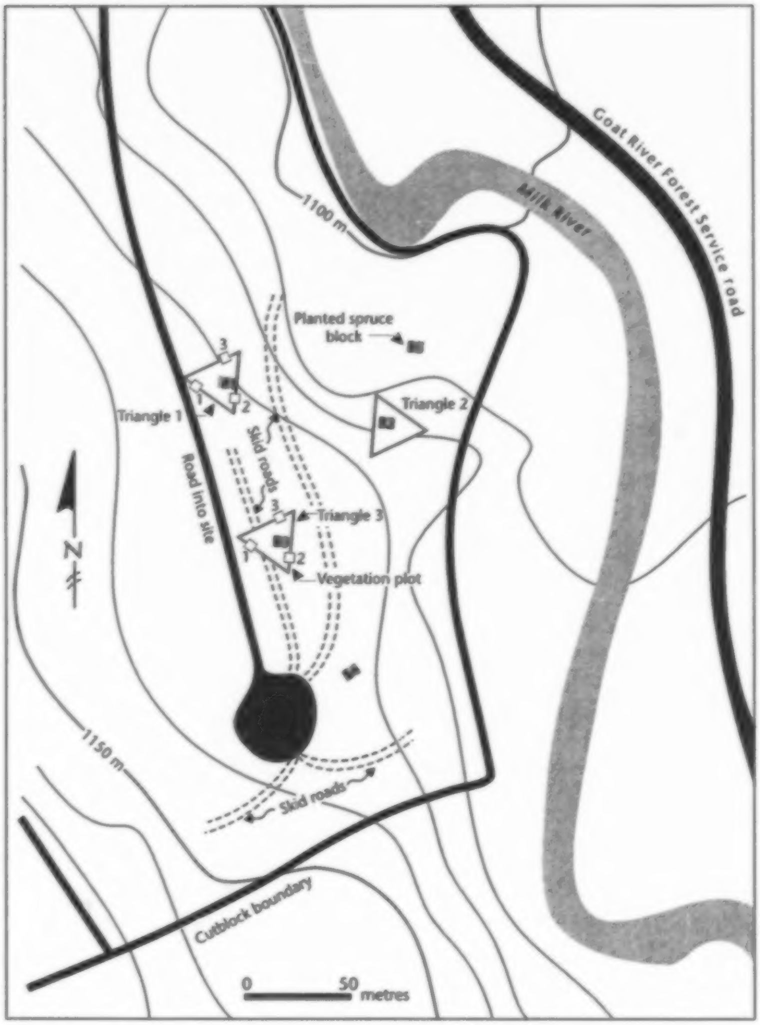

FIGURE 2 *Layout of vegetation plots, planted spruce tree blocks, and fuel measurement triangles on the site. (Numbers beside vegetation plots and within planted spruce blocks indicate the plot or block number, respectively.)*

The site is on level to gently sloping (12%) terrain that has a northeast aspect. Soils are clay loam to silty clay loam textured podzols derived from colluvium over fluvial parent materials. The LFH layer was 4–6 cm thick prior to burning.

The site was clearcut in the winter of 1987–1988 when snow cover was deep enough to prevent disturbance of the forest floor or destruction of understorey vegetation on most of the site. Broadcast burning took place on August 26, 1988, and spruce seedlings were planted in the spring of 1989.

A separate trial was set up to monitor the effects of mechanical site preparation (hand mounding) on planted spruce growth on this site (Hunt 1997).

2.1 Field Data Collection

2.1.1 Fire weather, duff, and fuel measurements Three fuel measurement triangles were sampled on June 27 and 28, 1988, following the methods outlined by Trowbridge et al. (1994) (Figure 3). Thirty depth-of-burn pins were installed along the sides of each triangle. Nine additional pins were installed in each vegetation plot, for a total of 27 extra pins per triangle. Total number of pins on the site was 144. The litter layer depth was measured prior to burning. Depth of burn was determined at each pin after the site was burned. Remaining duff depth was also determined and used to calculate percent duff consumption. A few pins could not be relocated and were therefore not re-measured after burning. Mineral soil exposure was estimated before and after burning.

Data from a fire weather station located nearby in McBride were used to calculate CFFWIS codes and indices following standard procedures (van Wagner 1987).

Gravimetric samples were taken from the clearcut to determine forest floor (duff) moisture content. Fifteen samples of the forest floor (0–5 cm and 5–10 cm layers) were collected in metal tins immediately before burning on August 26, 1988. Samples were weighed before and after drying in a forced-air convection oven at 70°C for 24 hours.

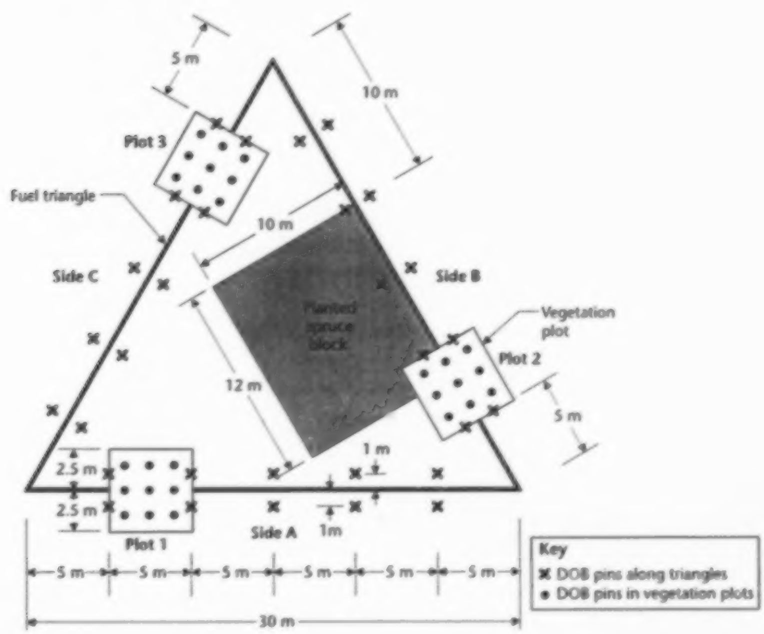

FIGURE 3 *Layout of vegetation plots, planted spruce blocks, depth-of-burn (DOB) pins, and fuel measurement triangles.*

2.1.2 Vegetation sampling Six 5 × 5 m permanent plots were established in the summer of 1988 after logging, but before slashburning occurred (Figure 2). The plots were superimposed on two of the three fuel measurement triangles (Figure 3).

Pre-burn vegetation data were collected in June 1988. Post-burn data were collected in late July or August of 1989, 1990, 1991, 1993, and 1998, which corresponded to the end of first, second, third, fifth, and tenth growing seasons after burning (referred to subsequently as "years after burning"). All vascular plant species and common bryophyte cover and presence were recorded. The mode of establishment (i.e., from buried or surface seed, or resprouting from surviving plant parts) was noted for vascular plant species in 1989. The origin of plants was determined by very carefully excavating around the root to determine if it was attached to an existing plant (i.e., new plant was of vegetative origin) or if the plant was a new seedling. In the case of seedlings, the depth of the seed from which it originated was estimated from the morphology of the germinant; in this way, germinants could be classified as originating from buried seeds (seed bank) or from more recent seed rain. The substrate (i.e., organic or mineral soil) from which seeds originated was also noted.

An ocular estimate of the percent cover of each plant species was recorded in each plot. Modal height (an estimate of average height that takes into account the proportion of cover of individual plants of different heights) was recorded for selected herb and shrub species only. In 1993 and 1998, the flowering stems were not included in height measurements of two tall herbs (*Carex* sp. and *Epilobium angustifolium*). Estimates of height for these species in 1993 and 1998 are therefore not entirely comparable to those of other years.

Percent cover for all species (i.e., total cover) was recorded in the field from 1989 to 1998. Total vegetation height was recorded in 1989 and 1990 and an estimate based on individual species height measurements was provided in 1988, 1993, and 1998. Bryophytes were included in total percent cover estimates, but not in height estimates. Coniferous trees were not included in the calculation of total vegetation height.

Total shrub cover, total herb cover, and total bryophyte cover were derived by using the sum of individual species cover values from 1988 to 1991, with some reduction due to an estimation of overlap of layers In 1993 and 1998, these values were recorded in the field. Total shrub and herb heights were derived from heights of the individual species using a weighting procedure for all years except 1993 when these total values were recorded in the field (details available from the author on request). Average height of the total herb layer was based on heights of *Epilobium angustifolium* and *Carex* sp. Total tree cover and heights were based on individual tree species values.

2.1.3 Tree seedling sampling The entire cutblock was planted with hybrid white spruce seedlings (stocktype 1+0 PSB313). Two hundred and twenty seedlings were planted in five experimental seedling blocks and then tagged. Three of the seedling blocks were located within the three fuel measurement triangles (Figure 3). Seedlings planted in blocks 1–3 (within the triangles) were planted at 2 × 2 m spacing, whereas those in blocks 4 and 5 were planted at 1.7 × 1.7 m spacing.

Planted spruce seedlings were measured immediately after planting in May 1989, and again in October 1990, August 1993, and August 1998 (2, 5, and 10 years after planting). Height, root collar diameter, and two perpendicular

diameters of the crown (measured from tip to tip of branches at the widest part of the crown) were measured. The crown measurements were used to calculate crown area using the formula πr^2, where r (radius) is the mean of the two crown diameter measurements/2. The cover of trees (*Abies lasiocarpa* and *Tsuga heterophylla* advance regeneration in 1988 and planted spruce seedlings from 1991 onwards) was recorded. An operational assessment of free-growing status was done by the McBride (now Headwaters) Forest District on November 24, 1998.

2.2 Data Analysis

Mean cover, mean height, and percent presence were calculated for individual plant species over all sample plots. Graphs were used to present the changes in vegetation and planted spruce that have taken place. Differences in seedling survival in the five blocks were evaluated using a Chi-square test. The mean depth of burn associated with the three fuel measurement triangles was compared using a t-test and 95% confidence limits.

Measured forest floor moisture content (MC) was converted to an equivalent DMC (eDMC) and DC (eDC) using the conversion formulas for various forest types in Lawson et al. 1997a and Lawson et al. 1997b. Actual duff and fuel consumption and mineral soil exposure were compared to values predicted by the Prescribed Fire Predictor (PFP) (Muraro 1975) with eDMC used as an input. Fuel consumption was calculated using standard Ministry of Forests programs (Ember Research Services 1997).

3 RESULTS

3.1 Fire Monitoring and Fire Effects

3.1.1 Conditions at the time of burning The site was burned using helicopter drip torch ignition on August 26, 1988. The CFFWIS codes and indices calculated using the McBride fire weather station data were Fine Fuel Moisture Content (FFMC) = 91, Duff Moisture Code (DMC)[1] = 33, and Drought Code (DC) = 509 (Table 1). The relative humidity was 36% and the air temperature was 26°C.

The measured moisture content of the forest floor in the cutblock was 84% for the 0–5 cm layer and 106% for the 5–10 cm layer. If the DMC is taken to correspond to the moisture content of the loosely compacted forest floor at a depth of approximately 7 cm (Lawson et al. 1997a), then the data for the 5–10 cm layer would be used for comparison.

This site most closely resembles the Yukon pine/white spruce – Feathermoss – Sphagnum and Undifferentiated duff forest type (Equation 3) in Lawson et al. 1997a and the White spruce duff forest type (Equation MC-6) in Lawson et al. 1997b. The observed moisture content of the 5–10 cm layer (106%) corresponds to an eDMC of 55 when Equation 3 is used (Table 1) and to an equivalent DC (eDC) of 409 when Equation MC-6 is used.

The DMC based on the McBride fire weather station data or WDMC was 33, which corresponds to a forest floor moisture content of 176%, based on Equation 3 (Table 1). The DC was 509, which corresponds to a forest floor moisture content of 73% based on Equation MC-6.

1 This DMC will be referred to as the weather station DMC or WDMC.

TABLE 1 *Canadian Forest Fire Weather Index System (CFFWIS) codes and indices[a] at time of ignition, and corresponding measured fuel and forest floor moisture content*

Source of measured data	Moisture content (%) (mean ± 95% c.l.)	CFFWIS codes and indices: FFMC	CFFWIS codes and indices: DMC (mean ± 95% c.l.)	CFFWIS codes and indices: DC
	Predicted		Measured	
McBride weather data	176[b]	91	33	509
	Measured		Predicted (eDMC)	
Gravimetric sampling of duff in the cutblock				
0–5 cm layer (n = 15)	84 (76–92)		55 (52–58)[c]	
5–10 cm layer (n = 15)	106 (98–114)		48 (46–50)[c]	

a Canadian Forest Fire Weather Index System (CFFWIS) codes and indices: FFMC = Fine Fuel Moisture Content; DMC = Duff Moisture Code; DC = Drought Code.

b Corresponding moisture content of 5–10 cm layer when DMC is 33 (based on Equation 3 in Lawson et al. 1997a: MC = exp[DMC −157.3/−24.6]+20).

c Corresponding eDMC based on Equation 3 in Lawson et al. 1997a (mean and 95% confidence limits [c.l.]).

3.1.2 Fuel and forest floor consumption Fuels were predominantly subalpine fir (41 tonnes/ha) and Engelmann spruce (3 tonnes/ha) with some hemlock slash. Average pre-burn fuel loading was 58.4 tonnes/ha; 26% of the woody fuel was consumed (Table 2).

Initially the forest floor was 6.3 cm deep, of which 2.5 cm was litter. Average depth of burn was 1.0 cm and consumption was 16.5% (Table 3). Post-burn mineral soil exposure was 2.7% (Table 5).

Average forest floor consumption was lower in the triangle 1 (T1) vegetation plots (mean = 0.26 cm; SE = 0.13) than in the triangle 3 (T3) vegetation plots (mean = 0.58 cm; SE = 0.13); however, the difference was not significant ($p = 0.05$) (Table 4). Relatively little difference was evident in average depth of burn in any of the three fuel measurement triangles. In T1, 10 of 28 depth-of-burn pins were "unburned" (i.e., heat scorched, but with no measurable duff consumption), whereas only 1 of 27 pins in T3 was "unburned" (Table 4).

Observed duff and fuel consumption and mineral soil exposure were less than that predicted by the PFP. This was true regardless of whether the value used as input was derived from measured forest floor moisture content (eDMC) or from the McBride weather station values (wDMC) (Table 5).

Measured woody fuel consumption was somewhat less than that predicted by the PFP using the wDMC used as input. The prediction based on the eDMC was higher than that observed or predicted using the wDMC.

TABLE 2 *Pre- and post-burn woody fuel loading and consumption*

Variable	Pre-burn loading (t/ha)	Post-burn loading (t/ha)	Consumption (%)
Total woody fuel	58.4	43.3	25.8
< 7 cm fuel	16.5	7.6	54.1
> 7 cm fuel	41.9	35.8	14.7

TABLE 3 *Pre- and post-burn depth of total LFH, litter, and FH layers, and depth of burn*

Variable	Pre-burn depth (cm)	Post-burn depth (cm)	Depth of burn (cm)
Total LFH layer	6.3	5.3	1.0
Litter layer	2.5	1.5	1.0
FH layer (duff)	3.8	3.8	0

TABLE 4 *Depth of burn for each vegetation plot within a fuel triangle, for the corresponding side of each fuel triangle, and the average for each fuel triangle*

Triangle no.	Plot	Mean DOB (cm)	SE	*n*	Number "unburned" pins	Triangle side	Mean DOB (cm)	SE	*n*
Triangle 1	1–1	0.04	0.03	9	4	A	1.20	0.53	10
Triangle 1	1–2	0.74	0.34	9		B	2.61	1.06	9
Triangle 1	1–3	0.00	0.00	9	6	C	0.55	0.29	10
Average		**0.26 a***	**0.13**				**1.41 b**	**0.41**	
Total n				**27**	**10**				**29**
Triangle 2						A	1.20	0.46	10
Triangle 2						B	1.69	0.76	8
Triangle 2						C	1.60	0.47	10
Average							**1.48 b**	**0.31**	
Total n									**28**
Triangle 3	3–1	0.31	0.21	9	1	A	0.44	0.27	9
Triangle 3	3–2	0.56	0.12	9		B	1.89	0.60	9
Triangle 3	3–3	0.87	0.30	7		C	1.50	0.51	9
Average		**0.58 a**	**0.13**				**1.28 b**	**0.29**	
Total n				**25**	**1**				**27**

* Average depth of burn (DOB) for triangles that have the same letter after the mean in the same column are not significantly different (p = 0.05). Average depth-of-burn measurements for the same triangle derived using different methods (i.e., plots vs. triangle sides) were not compared.

TABLE 5 *Actual and predicted duff and fuel consumption, and mineral soil exposure, using weather station and measured forest floor moisture content*

	Duff consumption (%)		Mineral soil exposure (%)		Total fuel consumption (%)	
Method	Predicted[a]	Actual	Predicted	Actual	Predicted[b]	Actual[c]
McBride fire weather station WDMC = 33	60	22	50	2.7	35	26
Measured forest floor moisture content eDMC = 48 (95% c.l. = 46–50)	70	22	60	2.7	40	26

a Based on Prescribed Fire Predictor (Muraro 1975).
b Predicted consumption of woody fuels less than 22 cm in diameter.
c Actual consumption of all woody fuels.

3.2 Vegetation

3.2.1 Floristic composition Before burning, there were three tree, seven shrub, seven herb, and eight bryophyte taxa on the site. Ten years after burning, 2 tree, 9 shrub, 16 herb, and 6 bryophyte taxa were present (Table 6). The increase in total number of taxa (from 25 pre-burn to 33 by year 10) was due to the establishment of new herb and shrub taxa typical of early forest succession. Seventeen of the 22 taxa found before burning were present 10 years after the site was burned. Twenty new colonizing taxa originated both from off-site sources and from on-site buried seeds. Some of the new colonizers were observed sporadically and were not evident in year 10. In general, few pre-burn vascular taxa were lost from the plots and some that were lost initially reappeared.

TABLE 6 *Number of taxa by life form and sample year*

	Life form				
Year	**Trees**	**Shrubs**	**Herbs**	**Bryophytes**	**Total number per year**
1988	3	7	7	8	25
1989	1	9	7	7	24
1990	1	10	9	6	26
1991	1	10	9	7	27
1993	1	8	11	8	28
1998	2	9	16	6	33

3.2.2 Changes in abundance, composition, and structure Total vegetation cover decreased from 95% pre-burn to 35% in the first post-burn year, then increased to 92% by 1998 (Table 7; Figure 4). Although herb and shrub cover initially decreased sharply, both exceeded pre-burn levels by year 2. After logging, the vegetation community was dominated by bryophytes (82% cover), with 24% herb cover and 6% shrub cover. By 1998 it was a conifer-shrub-herb-bryophyte community (Figures 4–8).

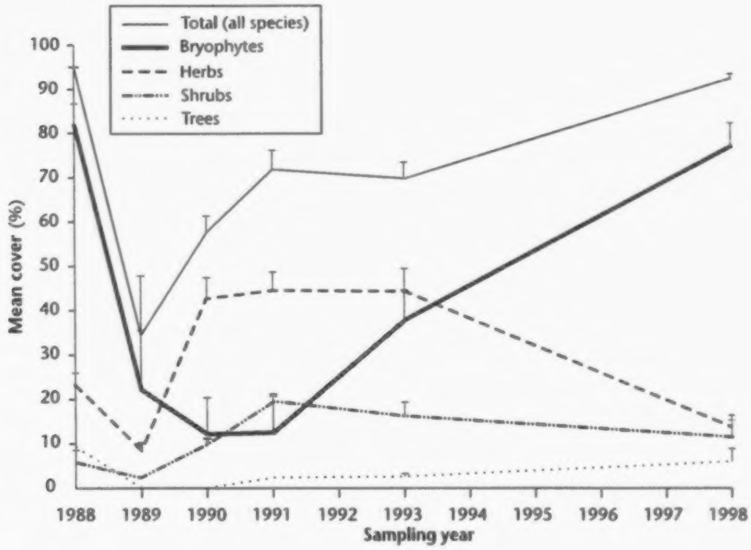

FIGURE 4 *Mean percent cover of life forms over time (vertical lines represent standard error bars).*

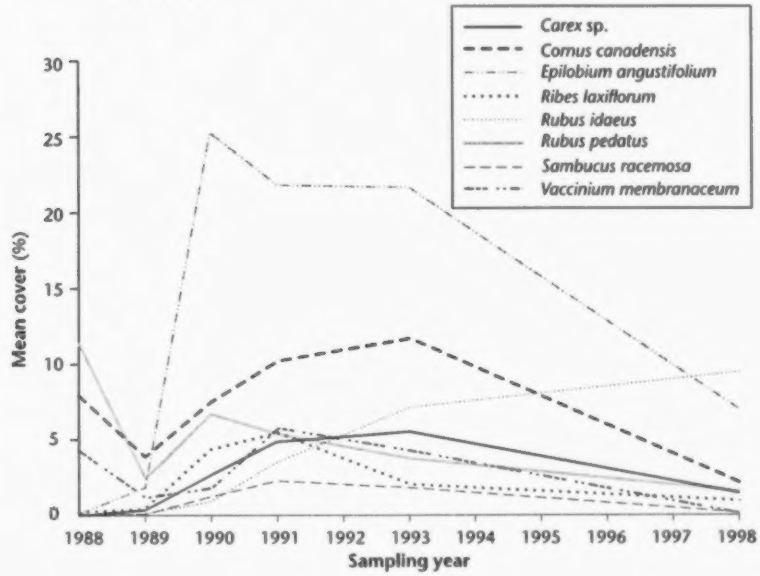

FIGURE 5 *Mean percent cover of selected species over time.*

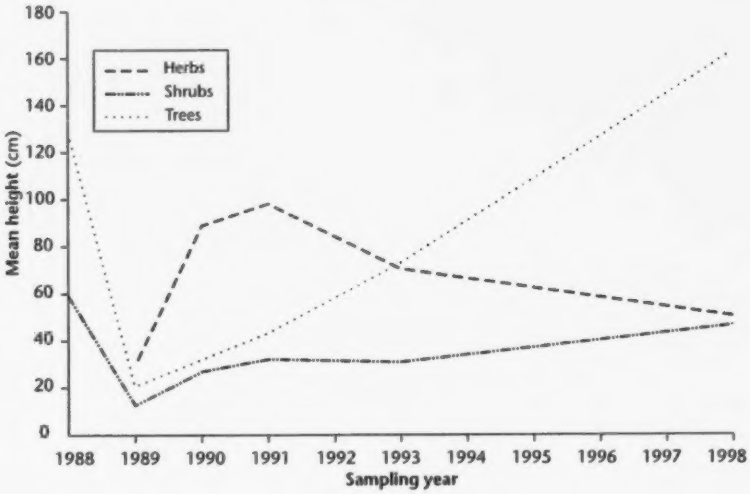

FIGURE 6 *Height of life forms over time.*

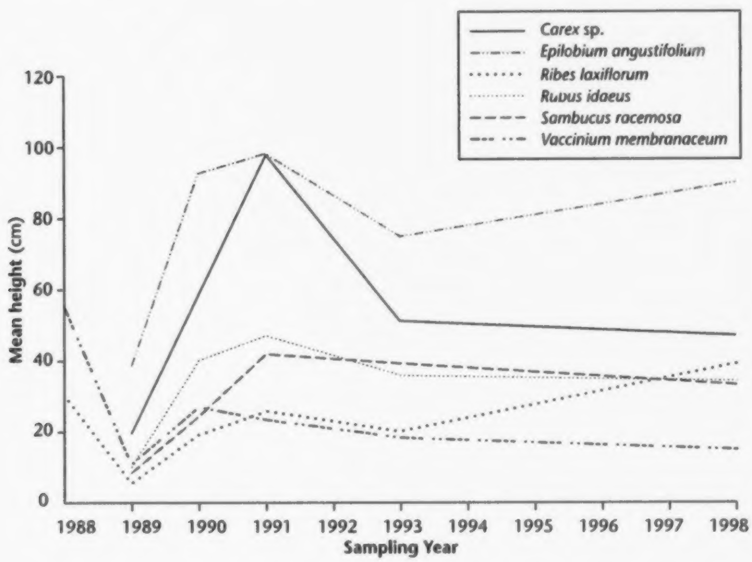

FIGURE 7 *Height of selected species over time.*

TABLE 7 *Mean percent cover and mode of origin of species observed in 1989, and percent presence of all species by year*

	Mean cover (%)						Presence (%)					
	Pre-burn	Post-burn					Pre-burn	Post-burn				
	1988	1989	1990	1991	1993	1998	1988	1989	1990	1991	1993	1998
Trees												
Abies lasiocarpa	8.18						100					
Tsuga heterophylla	1.00						33.3					
Picea glauca × engelmannii	0.02	0.17	0.17	2.33	2.67	6.00	16.7	16.7	16.7	100	100	83.3
Betula papyrifera						0.02						16.7
Total trees	**9.20**	**0.17**		**2.33**	**2.67**	**6.02**						
Shrubs												
Menziesia ferruginea	0.83	0.25 R[a]	0.12	0.52		0.02	33.3	33.3	33.3	50		16.7
Rhododendron albiflorum	0.33	0.08 R	0.03	0.08			16.7	16.7	16.7	16.7		
Vaccinium membranaceum	4.33	1.17 R	1.75	5.75	4.25	0.03	100	83.3	100	100	100	33.3
Ribes laxiflorum	0.17	0.32 SB/R	4.33	5.50	2.08	0.95	16.7	100	100	100	100	100
Sorbus scopulina	0.83	0.25 R	0.50	0.67	0.42	0.33	33.3	33.3	33.3	33.3	33.3	33.3
Vaccinium ovalifolium	0.02	0.02 R	0.67	0.83	0.17	0.08	16.7	16.7	16.7	16.7	16.7	16.7
Rubus idaeus		0.15 SB	0.90	3.50	7.17	9.50		83.3	83.3	83.3	100	100
Sambucus racemosa		0.08 SB	1.27	2.25	1.83	0.20		83.3	83.3	83.3	100	50
Ribes lacustre[c]	+[b]	0.10 SB/R	0.17	0.17	0.08		[16.7][c]	33.3	16.7	16.7	16.7	
Rubus parviflorus			0.08	0.10	0.03	0.03			16.7	33.3	33.3	33.3
Salix sp.					0.17	0.50					16.7	16.7
Total shrubs	**6.51**	**2.42**	**9.82**	**19.37**	**16.20**	**11.64**	**100**	**100**	**100**	**100**	**100**	**100**
Herbs												
Cornus canadensis	8.00	3.83 R	7.50	10.17	11.67	2.17	100	100	100	100	100	100
Rubus pedatus	11.33	2.43 R	6.70	5.33	3.75	1.58	100	100	100	100	100	100
Gymnocarpium dryopteris	1.67	0.17 R	0.33	2.02	1.08	0.37	50	16.7	16.7	33.3	33.3	83.3
Dryopteris expansa	0.50	0.10 R	0.27	0.17	0.18	0.03	33.3	33.3	50	33.3	50	33.3
Lycopodium annotinum	1.85		0.02	0.10	0.03	0.18	83.3		16.7	33.3	33.3	33.3
Streptopus lanceolatus	0.17		0.02	0.10	0.25		16.7		16.7	33.3	33.3	
Epilobium angustifolium		1.93 S	25.33	21.83	21.83	7.00		100	100	100	100	100
Carex sp.		0.35 SB	2.67	4.85	5.50	1.42		50	66.7	66.7	66.7	83.3
Athyrium filix-femina[c]	+[b]	0.02 R				0.02	[16.7][c]	16.7				16.7
Epilobium ciliatum			0.08						16.7			
Anaphalis margaritacea				0.02	0.02					16.7	16.7	
Cirsium sp.					0.02	0.33					16.7	16.7
Hieracium albiflorum					0.03	0.30					33.3	100
Aster sp.						0.02						16.7
Calamagrostis canadensis						0.33						16.7
Galium triflorum						0.02						16.7

TABLE 7 *Continued*

	Mean cover (%)						Presence (%)					
	Pre-burn	Post-burn					Pre-burn	Post-burn				
	1988	1989	1990	1991	1993	1998	1988	1989	1990	1991	1993	1998
Herbs, continued												
Poaceae						0.03						33.3
Stellaria sp.						0.02						16.7
Taraxacum officinale						0.03						33.3
Total herbs	**23.52**	**8.83**	**42.92**	**44.59**	**44.20**	**13.85**	**100**	**100**	**100**	**100**	**100**	**100**
Bryophytes												
Mnium sp.	0.02						16.7					
Hylocomium splendens	22.83	0.33	0.17				100	33.3	16.7			
Ptilium crista-castrensis	33	8.52	1.03	1.08	4.33	6.00	100	50	50	50	50	66.7
Pleurozium schreberi	10.17	0.68	2.50	2.50	3.92	8.83	100	50	50	50	66.7	83.3
Sphagnum sp.	12.35	11.68	8.33	8.33	0.33		50	33.3	16.7	16.7	16.7	
Dicranum sp.	0.18	0.17	0.03	0.03	0.33		33.3	16.7	16.7	16.7	33.3	
Polytrichum commune	0.5			0.02	1.68	13.33	33.3			16.7	33.3	16.7
Polytrichum sp.				0.33	8.83	45.00				16.7	83.3	83.7
Barbilophozia lycopodioides	3	0.68			0.10	0.02	100	50			33.3	16.7
Ceratodon purpureus					18.33	0.22					100	66.7
Marchantia polymorpha		0.35	0.18	0.25				33.3	33.3	33.3		
Total bryophytes	**82.05**	**22.41**	**12.24**	**12.54**	**37.85**	**77.23**	**100**	**100**	**100**	**100**	**100**	**100**
Grand Total	100	34.7	57.5	71.7	70	100	100	100	100	100	100	100

a Mode of origin: SB = seed bank (buried seed); S = seed (buried or new); R = resprout of existing plants.

b Species recorded as a resprout in one plot in 1989, but not noted in 1988 pre-burn sampling, probably because it was overlooked.

c Assumed frequency of occurrence in 1988 based on observation of resprouts in 1989.

Herb cover and height increased because of the influx and expansion of colonizers (especially *Epilobium angustifolium* and *Carex* sp.) and then dropped as these species declined. Shrub cover declined after burning and then increased to about double the pre-burn values, primarily because of the expansion of the colonizing *Rubus idaeus* (Table 7; Figures 5–7; Appendices 2 and 3).

3.2.3 Individual species responses All seven of the original shrub species resprouted after the fire. *Vaccinium membranaceum* was the dominant shrub species before burning. It recovered to pre-burn cover levels by year 3 and then virtually disappeared by year 10. *Rhododendron albiflorum* and *Menziesia ferruginea* had declined significantly or disappeared by year 10; however, neither was abundant before burning. *Ribes laxiflorum*, present in only one plot before burning, colonized all other plots the first year after burning primarily through germination of buried seed. *Ribes lacustre* also resprouted

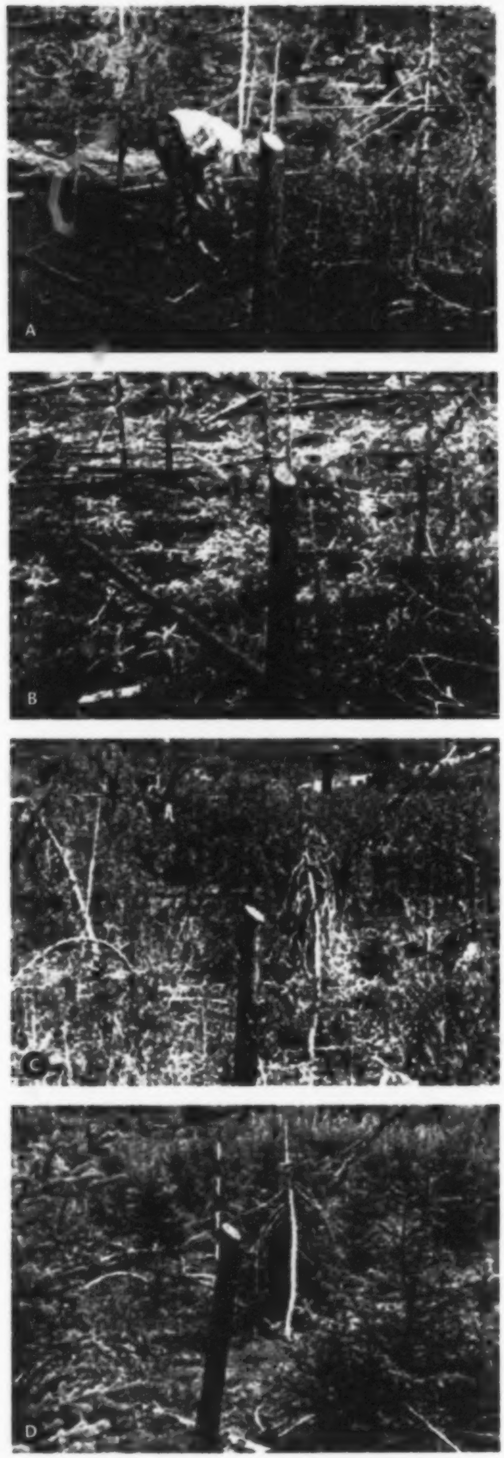

FIGURE 8 *Photos of the site (A) immediately after burning, and (B) year 1, (C) year 5, and (D) year 10 after burning.*

and established from buried seed, although germinants were not nearly as common as those of *Ribes laxiflorum*.

Four new shrub species (*Rubus idaeus, Sambucus racemosa, Rubus parviflorus*, and *Salix* sp.) established after burning. The first three established through germination of buried seeds, and although many germinants died, the species initially increased in abundance. Only *Rubus idaeus* continued to increase in cover and presence up to year 10. *Salix*, which was not apparent until year 5, established from off-site seed sources (Figures 5 and 7; Appendix 2).

Most of the herb species noted before burning resprouted after the fire and persisted. *Cornus canadensis* and *Rubus pedatus* were the most abundant herbs before burning. Both of these species increased and then declined in cover. *Rubus pedatus* had not recovered to pre-burn levels by year 10. *Epilobium angustifolium* occupied all plots by the first year after burning and dominated the site thereafter. *Streptopus lanceolatus* and *Lycopodium annotinum* reappeared by year 2. Twelve new herb species established from off-site seed sources. *Carex* sp. germinated from buried seed (Table 7; Figure 5; Appendix 2).

Four of the original eight bryophyte taxa were still present 10 years after the fire. *Hylocomium splendens*, the second most abundant moss before burning, persisted only until 1990. *Sphagnum* sp. declined in abundance over time. *Polytrichum* sp. proliferated after burning. None of the other taxa found before burning fully recovered in either abundance or frequency.

3.3 Planted Spruce

3.3.1 Survival Average survival of the hybrid white spruce seedlings after 10 growing seasons was 77%, but varied considerably between blocks (Table 8). In most blocks, mortality occurred the first year after planting. No significant difference was evident in burn impact between block 1 and block 3, or subsequently in seedling survival between the two blocks ($p = 0.05$) (Table 8).

TABLE 8 *Survival of planted spruce seedlings over time*

		Year				
		1989	1990	1993	1998	
Block number	Triangle number	Number planted	Survival (%)	Survival (%)	Survival (%)	Standard error and significance[*]
4	n/a	47	64	57	57	0.072 a
3	3	42	79	69	69	0.071 ab
1	1	42	71	71	71	0.070 ab
2	2	42	98	93	90	0.045 bc
	n/a	47	98	98	98	0.021 c
Mean			82	78	77	
Total		220				

[*] Blocks that have the same letter did not differ in terms of survival of seedlings ($p = 0.05$).

3.3.2 Height, diameter, and crown area growth By the end of 10 growing seasons, hybrid white spruce seedlings were on average 186.8 cm in height and 5.2 cm in diameter at the root collar; the seedlings had an average crown area of 9810 cm^2 (Table 9).

TABLE 9 *Tree seedling height, root collar diameter, and crown area by block at the time of planting and 2, 5, and 10 years after burning*

	Mean ± SE				
	1989	Year 2 (1990)	Year 5 (1993)	Year 10 (1998)	Significance[a]
Height (cm)					
Block 1	18.1 ± 0.6	40.6 ± 1.2	74.3 ± 3.5	213.9 ± 7.8	b
Block 2	16.5 ± 0.5	37.8 ± 1.2	61.5 ± 3.1	195.1 ± 10.0	b
Block 3	16.9 ± 0.4	39.1 ± 1.4	72.6 ± 3.6	149.1 ± 9.17	a
Block 4	19.2 ± 0.4	38.7 ± 1.4	73.8 ± 3.6	178.5 ± 14.5	ab
Block 5	22.5 ± 0.7	36.5 ± 2.1	71.4 ± 6.2	197.2 ± 7.15	b
Mean	**18.0 ± 0.3**	**38.9 ± 0.6**	**71.2 ± 1.6**	**186.8 ± 9.72**	
Root collar diameter (cm)					
Block 1	0.30 ± 0.09	0.72 ± 0.21	1.83 ± 0.57	5.99 ± 1.90	c
Block 2	0.28 ± 0.08	0.69 ± 0.19	1.71 ± 0.55	4.95 ± 2.28	ab
Block 3	0.43 ± 0.14	0.73 ± 0.18	1.95 ± 0.70	4.47 ± 2.56	a
Block 4	0.45 ± 0.09	0.71 ± 0.16	1.87 ± 0.54	5.15 ± 2.13	abc
Block 5	0.42 ± 0.16	0.67 ± 0.35	1.70 ± 1.43	5.44 ± 3.42	bc
Mean	**0.37 ± 0.07**	**0.71 ± 0.09**	**1.83 ± 0.30**	**5.2 ± 2.46**	
Crown area (cm^2)					
Block 1	21 ± 1.3	315 ± 20	1448 ± 95	12399 ± 517	c
Block 2	14 ± 1.1	286 ± 23	1071 ± 103	9780 ± 565	ab
Block 3	18 ± 1.2	271 ± 18	1380 ± 102	7961 ± 1238	a
Block 4	21 ± 0.9	264 ± 18	1525 ± 118	8358 ± 810	a
Block 5	17 ± 1.2	230 ± 37	1292 ± 235	10555 ± 568	abc
Mean	**19.0 ± 0.6**	**281 ± 10**	**1369 ± 53**	**9810 ± 740**	

[a] Seedling attributes (i.e., height, root collar diameter, or crown area) in blocks that have the same letter were not significantly different in 1998 ($p = 0.05$).

3.3.3 Relationship of tree growth to burn effects and vegetation levels By 1998, the vegetation in the plots associated with fuel measurement triangle 3 was taller than that in triangle 1 (Tables 10 and 11). Triangle 3 had been burned more completely and deeply (although not statistically significantly deeper) than triangle 1, which was more patchily burned (Tables 4 and 11). By year 10, seedlings in block B1 were taller than B3 seedlings, they had larger root collar diameters than those in block B3, and the crown area of seedlings in block B1 was greater than that of seedlings in block B3 ($p = 0.05$).

TABLE 10 *Cover and height statistics (mean ± standard error) for selected life forms and species, by year*

	Post-burn cover (%)				
Life form	**1989**	**1990**	**1991**	**1993**	**1998**
Triangle 1 shrubs	1.9 ± 0.3	8.8 ± 1.8	20.7 ± 1.7	20.5 ± 5.2	13.7 ± 7.0
Triangle 1 herbs	9.8 ± 2.2	36.8 ± 6.8	37.6 ± 4.0	38.4 ± 6.5	15.2 ± 4.7
Triangle 1 bryophytes	42.5 ± 21.6	22.1 ± 15.2	22.2 ± 15.3	47.4 ± 10.8	83.8 ± 1.3
Triangle 3 shrubs	2.9 ± 0.5	10.8 ± 2.2	18.0 ± 3.5	11.9 ± 2.1	9.6 ± 3.9
Triangle 3 herbs	7.9 ± 1.8	49.1 ± 4.3	51.6 ± 4.5	50.0 ± 7.9	12.5 ± 3.2
Triangle 3 bryophytes	2.4 ± 1.4	2.4 ± 1.9	2.9 ± 2.2	28.3 ± 4.4	70.7 ± 9.6
	Post-burn height (cm)				
	1989	**1990**	**1991**	**1993**	**1998**
Triangle 1 vegetation	19.2 ± 7.6	63.9 ± 16.1	–	49.0 ± 10.8	41.9 ± 8.8
Triangle 3 vegetation	29.3 ± 2.0	79.2 ± 8.1	–	61.0 ± 10.6	56.0 ± 9.6
Block 1 hybrid white spruce seedlings	18.9 ± 0.4	41.7 ± 1.1	–	79.0 ± 2.5	213.9 ± 7.6
Block 3 hybrid white spruce seedlings	16.8 ± 0.5	39.0 ± 1.4	–	65.9 ± 3.4	149.1 ± 9.2

TABLE 11 *Fire effects, vegetation variables, and hybrid white spruce seedling response 10 years after burning in triangles 1 and 3*

	Fire effects*		**Vegetation variables** (year 10)**		**Hybrid white spruce seedling response (year 10)**			
Triangle	DOB (cm)	Unburned pins	Total height (cm)	Total cover (%)	Survival (%)	Height (cm)	Diameter (cm)	Canopy area (cm^2)
T 1	0.26 a†	37 a	41.9 a	29 a	71 a	213 a	6.0 a	12 399 a
T 3	0.58 a	4 b	56.0 a	22 a	69 a	149 b	4.5 b	7961 b

* Based on pins in plots in triangles.
** Total shrub and herb cover and height.
† Numbers followed by the same letter were not significantly different (p = .05).

The burn was of fairly low severity compared with others monitored in similar ecosystems (Hamilton and Peterson 2003, 2006; Hamilton 2006a, 2006b). It was patchy, with very little mineral soil exposure and limited large fuel consumption. Some spots were only singed. The low severity of the burn was likely due to the light fuel loadings (i.e., 4.2 kg/m^2) on this ICH–ESSF transition site, compared with 8.5–15 kg/m^2 observed on other sites in the ESSF (Hamilton and Peterson 2003; 2006), in the SBS–ESSF transition (Hamilton 2006a), and on a SBS Devil's club site (Hamilton 2006b).

At the time of burning, the forest floor on the clearcut was drier than predicted using McBride weather station data, regardless of the equation used to convert duff moisture content to eDMC or the duff layer considered to be equivalent to the DMC layer (i.e. the 0–5 or 5–10 cm layer)(E.H. Hamilton, unpublished data). On other similar sites, except for Otter Creek, the forest floor was generally moister than predicted at the time of burning (Hamilton and Peterson 2003, 2006; Hamilton 2006a, 2006b).

The difference between observed and predicted moisture content found at Goat River may be due to a variety of factors including differences in weather on the site compared to McBride where the weather station was located. Although in the same subzone as McBride, the Goat River study site is about 30 km away and may have experienced differences in rainfall and evaporation that would explain the discrepancy between the measured forest floor moisture content and that predicted by the CFFWIS.

Samples used for determining eDMC were taken from both the 0–5 and 5–10 cm layer. The conversion equations used correspond to the moisture content of the 2–4 cm layer (or 2.5–4 cm in the case of the National Standard), although the DMC has been defined as corresponding to the moisture content at 7 cm (Lawson et al. 1997a). Although the Goat River site appeared to be most similar to the Pine/white spruce/feathermoss/sphagnum forest type, the measured moisture content of the 0–5 and 5–10 cm layers was closest to that predicted using the Southern Interior BC equation (Lawson et al. 1997a) to convert DMC to moisture content. The moisture content of the 5–10 cm layer was closer to that predicted by DMC than was that of the 0–5 cm layer. The white spruce duff (6–10 cm) equation (Equation MC-6) to convert DC to moisture content predicted moisture content of the 5–10 cm layer better than the National Standard equation (Lawson et al. 1997b). The best prediction for either layer was provided using the Southern Interior BC DMC conversion equation to predict moisture content of the 5–10 cm layer. On the other sites monitored, the best prediction of moisture content from DMC or DC in clearcuts was usually obtained using the DMC conversion equation for Pine/white spruce/feathermoss sites to predict moisture content in the 0–5 cm layer (E.H. Hamilton, unpublished data). In some cases the prediction was quite good, while in others there was significantly over- or under-prediction of moisture content. This variability points to the need to refine the CFFWIS for British Columbia forest types.

Observed duff and fuel consumption and mineral soil exposure were less than that predicted by the PFP. This was true regardless of whether the DMC value used as input was derived from measured forest floor moisture content (eDMC), with any of the conversion equations, or from the McBride weather station values (wDMC) (E.H. Hamilton, unpublished data). Predictions of

woody fuel consumption based on weather station data (WDMC) were closer to those observed than those based on the measured moisture content of the forest floor (EDMC). One would expect that predictions based on actual measurements of the forest floor moisture content to be more accurate than those based on predicted moisture content. The fact that this was not so suggests that the either the conversion equations do not provide accurate predictions of forest floor moisture content or the PFP does not perform well under the conditions observed on this site. Differences between observed and predicted duff and fuel consumption were also observed on other similar sites (Hamilton and Peterson 2003, 2006; Hamilton 2006a, 2006b).

On this site, woody fuel consumption predictions were more accurate than duff consumption predictions, regardless of the source of DMC values. This suggests that the PFP performs better at predicting woody fuel consumption rather than duff consumption on this type of site under these conditions. The results from other sites were highly variable, with good predictions of woody fuel consumption on some sites and not on others, and good predictions of duff consumption on some sites but not on others (Hamilton and Peterson 2003, 2006; Hamilton 2006a, 2006b). It is not clear why this is the case, but it points to the need for more work to develop the CFFWIS and PFP for these sites.

By 1998, the vegetation in the fuel measurement triangles that had been more completely burned was taller than that in the more patchily burned areas. This was likely due to the greater availability of seedbeds for fireweed, the dominant post-burn species, in the more completely burned plots. Taller vegetation was correlated with poorer tree growth (i.e., shorter seedlings with smaller diameter and canopy area) and lower survival. This was likely because of increased shading, reduced soil temperature and resource availability, and vegetation press (Coates et al. 1994). This level of vegetation, however, did not present a significant impediment to reforestation success, and the plantation was considered successfully regenerated 10 years after burning.

The vegetation community structure shifted from one that was dominated by mosses, herbs, and low shrubs, to one that was dominated by planted conifers. Similar patterns were observed on other nearby SBS, ESSF, and transitional ICH–ESSF–SBS sites after slashburning (Hamilton and Yearsley 1988; Hamilton and Peterson 2003, 2006; Hamilton 2006a, 2006b). Notable, however, was the absence of some fire-dependent seed-banking species (e.g., *Geranium bicknellii* and *Corydalis sempervirens*), which were common in the SBS (Hamilton and Yearsley 1988; Hamilton 2006b), but not on higher-elevation ESSF sites (Hamilton and Peterson 2003, 2006; Hamilton 2006a). The infrequent disturbance of ESSF forests landscapes (DeLong 1998) likely reduced the dispersal and/or survival of the seeds of these fire-dependent species, which are typically found for a short time immediately after burning on sites with fairly frequent fire return intervals (Bradley 2002).

All of the shrubs present before burning resprouted after the fire. The four new shrub species (*Rubus idaeus, Sambucus racemosa, Rubus parviflorus,* and *Salix* sp.) observed often colonize sites after burning or other disturbances (Haeussler et al. 1990). *Rubus idaeus, Sambucus racemosa,* and *Rubus parviflorus,* which established from seed banks, are known to be long-lived seed bankers (Haeussler et al. 1990). *Salix* seeds are generally too short-lived to form a seed bank, but are readily distributed to sites after fires (Haeussler et al. 1990). *Ribes laxiflorum* and *Ribes lacustre* both resprouted and established from buried seeds. Some of the original shrub species that declined in abundance over time (e.g., *Rhododendron albiflorum* and *Menziesia ferruginea*) are

known to be susceptible to burning (Haeussler et al. 1990; U.S. Department of Agriculture 2006).

All herb species present before burning resprouted after the fire. *Epilobium angustifolium* was the dominant herb after burning. A number of invasive herbaceous species (e.g., *Hieracium* sp. and *Cirsium* sp.) seeded-in over time. *Lycopodium annotinum*, which was very shallow-rooted and thus susceptible to destruction (U.S. Department of Agriculture 2006), was less common after the fire. *Carex* sp. established from buried seeds on this and other similar sites (Hamilton 2006b; Hamilton and Peterson 2006).

Although few species were absent after burning, the area sampled was fairly small (150 m^2). Rarer forest-dwelling species (e.g., orchids or *Monotropas*), which are known to be sensitive to burning (U.S. Department of Agriculture 2006), may have occurred on the site outside of the plots, and may have been negatively affected by burning.

Before burning, bryophytes were the dominant ground-level life form, but most were burned off by the fire. Although a number of the original forest bryophyte species disappeared, new species established and total bryophyte cover increased over time.

Although a few of the original vascular plant species were not observed again after burning, most species survived. Species in these ecosystems have various adaptations to enable them to re-establish or colonize after burning (Haeussler et al. 1990; U.S. Department of Agriculture 2006). The ericaceous shrubs, which are more typical of the ESSF zone, are less adapted than species more typical of lower-elevation SBS forests (e.g., *Sambucus racemosa*, and *Rubus* and *Ribes* species) (Haeussler et al. 1990; U.S. Department of Agriculture 2006). Historically, these lower-elevation forests experienced more frequent fires; therefore, the constituent species are more fire-adapted. On other sites, many species typical of the lower-elevation forests resprouted readily or established from buried seeds after a fire (Hamilton and Yearsley 1988; Hamilton and Hauessler 2005, 2006).

5 RECOMMENDATIONS

The following steps should be taken:

- Synthesis of fire effects, succession, and reforestation data from similar ecosystems in the province to provide better predictions of the effects of burning.
- Continued monitoring of sites to ensure the collection of long-term data.
- Better calibration of the CFFWIS and PFP to predict fire effects in British Columbia.

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APPENDIX 1 Scientific and common names of plant species encountered at the Goat River site

Scientific name[a]	Common name[b]
Abies lasiocarpa	subalpine fir
Anaphalis margaritacea	pearly everlasting
Aster sp.	aster
Athyrium filix-femina	lady fern
Barbilophozia lycopodioides	common leafy liverwort
Betula papyrifera	paper birch
Calamagrostis canadensis	bluejoint
Carex sp.	sedge
Ceratodon purpureus	fire moss
Cirsium sp.	thistle
Cornus canadensis	bunchberry
Dicranum sp.	
Dryopteris expansa	spiny wood fern
Epilobium angustifolium	fireweed
Epilobium ciliatum	purple-leaved willowherb
Galium triflorum	sweet-scented bedstraw
Gymnocarpium dryopteris	oak fern
Hieracium albiflorum	white-flowered hawkweed
Hylocomium splendens	step moss
Lycopodium annotinum	stiff club-moss
Marchantia polymorpha	green-tongue liverwort
Menziesia ferruginea	false azalea
Mnium sp.	leafy moss
Picea glauca × engelmannii	hybrid white spruce
Pleurozium schreberi	red-stemmed feathermoss
Polytrichum commune	common haircap moss
Polytrichum sp.	haircap moss
Ptilium crista-castrensis	knight's plume
Rhododendron albiflorum	white-flowered rhododendron
Ribes lacustre	black gooseberry
Ribes laxiflorum	trailing black currant
Rubus idaeus	red raspberry
Rubus parviflorus	thimbleberry
Rubus pedatus	five-leaved bramble
Salix sp.	willow
Sambucus racemosa	red elderberry
Sorbus scopulina	western mountain-ash
Sphagnum sp.	sphagnum
Stellaria sp.	starwort
Streptopus lanceolatus	rosy twistedstalk
Taraxacum officinale	common dandelion
Tsuga heterophylla	western hemlock
Vaccinium membranaceum	black huckleberry
Vaccinium ovalifolium	oval-leaved blueberry

a Scientific names follow the British Columbia provincial species list (Meidinger et al. 2004).
b Common names follow primarily Meidinger (1987). MacKinnon et al. (1992) was used for species not named in Meidinger (1987).

APPENDIX 2 Cover (%) statistics (mean ± standard error) for all species by year, arranged by life form and successional pattern

	Pre-burn	Post-burn				
	1988	1989	1990	1991	1993	1998
Trees						
Total trees	**9.20 ± 4.12**	**0.17 ± 0.17**		**2.33 ± 0.42**	**2.67 ± 0.56**	**6.02 ± 2.90**
Abies lasiocarpa	8.18 ± 3.79					
Tsuga heterophylla	1.00 ± 0.68					
Picea glauca × engelmannii	0.02 ± 0.02	0.17 ± 0.17		2.33 ± 0.42	2.67 ± 0.56	6.00 ± 2.90
Betula papyrifera						0.02 ± 0.02
Shrubs						
Total shrubs	**6.51 ± 2.07**	**2.42 ± 0.35**	**9.82 ± 1.36**	**19.37 ± 1.84**	**16.20 ± 3.17**	**11.64 ± 3.71**
Menziesia ferruginea	0.83 ± 0.65	0.25 ± 0.17	0.12 ± 0.08	0.52 ± 0.34		0.02 ± 0.02
Rhododendron albiflorum	0.33 ± 0.33	0.08 ± 0.08	0.03 ± 0.03	0.08 ± 0.08		
Vaccinium membranaceum	4.33 ± 1.48	1.17 ± 0.38	1.75 ± 0.57	5.75 ± 1.63	4.25 ± 2.24	0.03 ± 0.02
Ribes laxiflorum	0.17 ± 0.17	0.32 ± 0.15	4.33 ± 1.05	5.50 ± 0.85	2.08 ± 0.37	0.95 ± 0.36
Sorbus scopulina	0.83 ± 0.65	0.25 ± 0.17	0.50 ± 0.34	0.67 ± 0.49	0.42 ± 0.33	0.33 ± 0.21
Vaccinium ovalifolium	0.02 ± 0.02	0.02 ± 0.02	0.67 ± 0.67	0.83 ± 0.83	0.17 ± 0.17	0.08 ± 0.08
Rubus idaeus		0.15 ± 0.07	0.90 ± 0.46	3.50 ± 1.38	7.17 ± 2.82	9.50 ± 3.81
Sambucus racemosa		0.08 ± 0.02	1.27 ± 0.57	2.25 ± 0.83	1.83 ± 0.74	0.20 ± 0.16
Ribes lacustre		0.10 ± 0.08	0.17 ± 0.17	0.17 ± 0.17	0.08 ± 0.08	
Rubus parviflorus			0.08 ± 0.08	0.10 ± 0.08	0.03 ± 0.02	0.03 ± 0.02
Salix sp.					0.17 ± 0.17	0.50 ± 0.50
Herbs						
Total herbs	**23.52 ± 2.45**	**8.83 ± 1.33**	**42.92 ± 4.52**	**44.59 ± 4.13**	**44.20 ± 5.23**	**13.85 ± 2.63**
Cornus canadensis	8.00 ± 1.00	3.83 ± 0.87	7.50 ± 2.09	10.17 ± 1.99	11.67 ± 1.05	2.17 ± 0.74
Rubus pedatus	11.33 ± 1.76	2.43 ± 1.14	6.70 ± 3.49	5.33 ± 2.55	3.75 ± 1.39	1.58 ± 0.69
Gymnocarpium dryopteris	1.67 ± 1.28	0.17 ± 0.17	0.33 ± 0.33	2.02 ± 2.00	1.08 ± 0.99	0.37 ± 0.15
Dryopteris expansa	0.50 ± 0.34	0.10 ± 0.08	0.27 ± 0.17	0.17 ± 0.11	0.18 ± 0.10	0.03 ± 0.02
Lycopodium annotinum	1.85 ± 1.24		0.02 ± 0.02	0.10 ± 0.08	0.03 ± 0.02	0.18 ± 0.16
Streptopus lanceolatus	0.17 ± 0.17		0.02 ± 0.02	0.10 ± 0.08	0.25 ± 0.17	
Epilobium angustifolium		1.93 ± 0.60	25.33 ± 7.08	21.83 ± 5.69	21.83 ± 6.79	7.00 ± 1.90
Carex sp.		0.35 ± 0.21	2.67 ± 1.66	4.85 ± 2.78	5.50 ± 3.02	1.42 ± 0.45
Athyrium filix-femina		0.02 ± 0.02				0.02 ± 0.02
Epilobium ciliatum			0.08 ± 0.08			
Anaphalis margaritacea				0.02 ± 0.02	0.02 ± 0.02	
Cirsium sp.					0.02 ± 0.02	0.33 ± 0.33
Hieracium albiflorum					0.03 ± 0.02	0.30 ± 0.09
Aster sp.						0.02 ± 0.02
Calamagrostis canadensis						0.33 ± 0.33
Galium triflorum						0.02 ± 0.02
Poaceae						0.03 ± 0.02
Stellaria sp.						0.02 ± 0.02
Taraxacum sp.						0.03 ± 0.02

Appendix 2 *Continued*

	Pre-burn	Post-burn				
	1988	**1989**	**1990**	**1991**	**1993**	**1998**
Bryophytes						
Total bryophytes	**82.05 ± 4.70**	**22.41 ± 13.19**	**12.24 ± 8.14**	**12.54 ± 8.16**	**37.85 ± 6.75**	**77.23 ± 5.21**
Mnium sp.	0.02 ± 0.02					
Hylocomium splendens	22.83 ± 6.73	0.33 ± 0.21	0.17 ± 0.17			
Ptilium crista-castrensis	33.00 ± 10.25	8.52 ± 8.30	1.03 ± 0.81	1.08 ± 0.80	4.33 ± 3.23	6.00 ± 4.86
Pleurozium schreberi	10.17 ± 5.10	0.68 ± 0.49	2.50 ± 1.63	2.50 ± 1.63	3.92 ± 1.98	8.83 ± 5.28
Sphagnum sp.	12.35 ± 11.55	11.68 ± 11.66	8.33 ± 8.33	8.33 ± 8.33	0.33 ± 0.33	
Dicranum sp.	0.18 ± 0.16	0.17 ± 0.17	0.03 ± 0.03	0.03 ± 0.03	0.33 ± 0.21	
Polytrichum commune	0.50 ± 0.34			0.02 ± 0.02	1.68 ± 1.66	13.33 ± 13.33
Polytrichum sp.				0.33 ± 0.33	8.83 ± 3.11	45.00 ± 13.29
Barbilophozia lycopodioides	3.00 ± 0.89	0.68 ± 0.49			0.10 ± 0.08	0.02 ± 0.02
Ceratodon purpureus					18.33 ± 2.79	0.22 ± 0.16
Marchantia polymorpha		0.35 ± 0.33	0.18 ± 0.16	0.25 ± 0.17		
Total (all species combined)	**100**	**34.7 ± 13.16**	**57.5 ± 3.82**	**71.7 ± 4.41**	**70.0 ± 3.42**	**100 ± 1.12**

APPENDIX 3 Height (cm) statistics (mean ± standard error) for selected species

	Pre-burn	Post-burn				
	1988	1989	1990	1991	1993	1998
Trees	**129.9 ± 35.1**	**20.0 ± 0.0**		**43.3 ± 4.0**	**73.3 ± 7.2**	**164.4 ± 17.0**
Picea glauca × *engelmannii*	15.0 ± 0.0	20.0 ± 0.0		43.3 ± 4.0	73.3 ± 7.2	165.0 ± 17.1
Shrubs	**59.3 ± 7.1**	**2.8 ± 1.3**	**26.6 ± 1.8**	**32.1 ± 2.6**	**30.7 ± 4.7**	**46.5 ± 7.5**
Vaccinium membranaceum	55.0 ± 5.0	11.3 ± 1.3	26.7 ± 2.8	23.3 ± 1.7	18.3 ± 1.7	15.0 ± 0.0
Ribes laxiflorum	30.0 ± 0.0	5.3 ± 0.0	19.2 ± 0.8	25.8 ± 2.4	20.0 ± 1.3	39.2 ± 4.2
Rubus idaeus		10.0 ± 0.0	40.0 ± 0.9.1	47.0 ± 9.3	35.8 ± 8.0	34.2 ± 10.0
Sambucus racemosa		8.3 ± 1.7	24.4 ± 6.7	42.0 ± 7.0	39.2 ± 3.8	33.3 ± 8.8
Herbs		**29.6 ± 5.9**	**88.9 ± 9.6**	**97.8 ± 12.3**	**70.2 ± 7.4**	**50.4 ± 7.9**
Epilobium angustifolium		38.8 ± 5.2	92.5 ± 9.3	98.3 ± 12.0	75.0 ± 7.2	90.0 ± 2.6
Carex sp.		20.0 ± 5.8	58.8 ± 10.5	97.5 ± 11.6	51.3 ± 1.3	47.0 ± 4.6